

## Planetary Ring Dynamics and Morphology

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**F ring moonlet belt paper:** We are happy to have finished our long-overdue paper on the moonlet belt for which we find evidence in the region between Saturn's close-in ringmoons Pandora and Prometheus, the so-called F ring shepherds. In this paper, Cuzzi and J. Burns show how the little-noticed observations of magnetospheric electron density by Pioneer 11 imply substantial, ongoing injections of mass into the 2000 km region noted above which surrounds the F ring. We present a hypothesis that these events (which require the appearance of the mass equivalent of a 100 m radius ice particle every few hours) result naturally from interparticle collisions between the **smaller** members of an optically thin belt of moonlets. The moonlets in the belt may have radii ranging from about 100 meters to somewhat less than 10 km, and continually sweep up the ejecta produced by these collisions, keeping the F region relatively, but not completely, clear in steady state. We show that the **larger** members of this same population, numbering perhaps less than a dozen, produce much more massive clumps of particles when they collide, but that their collisions are far less common. In fact, it is possible to choose a reasonable parent size distribution that produces simultaneously the many small events responsible for the Pioneer electron density observations and rare large events that would lead to rings much like the F ring in mass and structure. These large clumps become strands when differential motion spreads the material longitudinally, and may exist for years before succumbing to the perpetual sweeping action of surrounding moonlets.

We thus raise the possibility that the F ring is not necessarily a primordial structure relying on "shepherding" by Pandora and Prometheus to keep it from spreading, but merely one of a series of transient features which come and go in response to occasional creation and continuing removal. The mysterious kinks in the F ring would be easily explained by occasional close passages by moonlets with sizes too small in general to be visible to the Voyager cameras, and its unusually small particle sizes by the fact that the F ring particles are really only a recently lost regolith produced initially by meteoroid bombardment. Even the multistranded nature of the F ring may be explained by this hypothesis, if the regoliths of two colliding bodies retain some memory of their pre-collision orbits.

We suspect that new insight into similar dynamical puzzles, such as incomplete ring arcs known to exist in Saturn's Encke gap and in the ring systems of Uranus and Neptune, will be gained from use of this theoretical framework. It may even help us understand the existence of the eight inner rings of Uranus, which seem to have no major shepherds to maintain them from spreading over the age of the solar system. These and the diffuse dust bands discovered by Voyager in the inter-Uranian-ring regions may indicate a situation similar to that which we describe for the F ring.

The concept of an intimate mix of rings and ringmoons in a highly interactive situation just outside Saturn's Roche limit, and the increasing evidence for moonlets embedded within Saturn's main rings (Showalter et al. 1986), provide us with new constraints on the properties of planetary ring systems. These new results seem to increasingly support some variation of the concept first presented by Shoemaker that sizeable moons precede or accompany ring formation, and that meteoroid bombardment of such moons, which is increasingly focussed and intense in regions closer to a planet, results in smaller and more numerous moon fragments closer to the planet. In addition, we suspect that more detailed future studies of the dynamical behavior of the F-region moonlet belt, which seems to lie outside Saturn's Roche limit, may have much to teach

us about planetary accretion.

**First erosion manuscript about half done:** We are about halfway through with the first of an anticipated series of papers on transport of mass and momentum by meteoroid ejection in planetary rings. The first paper (somewhat too rough to be distributed as yet) provides the theoretical framework of the numerical solution and some illustrative examples for certain simple ejecta distributions. It will describe how transport of mass and angular momentum by both ejecta and viscosity has been included in the formulation, and what typical results demonstrate. A companion manuscript will describe our development of the ejecta distribution in a realistic case including all known cratering ejecta distributions and accurate distributions of incident meteoroid flux which reflect aberrations due to the orbital motion of both Saturn and the ring particles, as well as the impact probability which depends on incident direction and velocity as well as on the optical depth of the local ring material. Extension of certain of these dynamical concepts has been made to demonstrate the inability of "late heavy bombardment" impacts to desynchronize satellite spins (Lissauer 1985).

**Uranus Ring ring structure and photometry:** We are conducting photometric analysis of the Uranian rings, working with others of the Voyager imaging team. The color of the rings has been carefully constrained using our image analysis system to average hundreds of pixels along the only barely visible rings. The improvement in SNR allows ring spectral contrast to be measured to the 15% level or so; the rings seem to have the same relatively colorless spectrum between 0.41 and 0.56 microns as the Uranian satellites and carbonaceous chondrites. In a complementary effort, we are analysing the Voyager images over the entire range of illumination and viewing geometry, using radiative transfer modeling to determine the dust content of the rings and the reflectance of the ring material. The dust content is extremely low in all nine main rings. The ring material is about as dark as the darkest primitive carbonaceous chondrites, and perhaps as dark as Halley. These new results are in agreement with pre-Voyager estimates reported last year (Cuzzi 1985). A paper on the ring color has been submitted to *Icarus*. One will shortly be written on the dust content and reflectance properties.

**Jupiter ring paper finished:** We have completed a paper describing our image processing and analysis of the Jovian ring system (enclosed), and the paper has been accepted for publication in *Icarus*. This work was primarily the thesis research of Mark Showalter, although general theoretical collaboration, radiative transfer modeling, and about half of the image processing were supported or materially aided under this RTOP. This task resulted in a significantly different view of the structure of the Jovian ring and the discovery of a new exterior "gossamer" ring, as reported last year.

**A ring photometry and structure:** Progress continues in photometric and structural studies of the A ring of Saturn. This work, primarily the thesis research of Luke Dones, is aimed at determining the distribution of "dust" as a dynamics tracer in and out of spiral density wavetrains in different regions of the A ring. Our ultimate goal here is to better understand the complex process of wave damping, which is less effective in higher optical depth regions due, according to a theory we developed under this grant, to the lower random velocities therein (Shu et al. 1985). We expect that these differences will manifest themselves in the fractional dust abundance. We have obtained improved constraints on the phase function and albedo of the macroscopic particles in the rings, and soon hope to solve for the dust fraction and its variation between unperturbed and perturbed regions.

Solution of this problem has been complicated by the poorly constrained azimuthally

variable brightness shown by the A ring; that is, in order to determine a phase curve that can constrain the fractional abundance of dust, we need first to determine how certain of the brightness observations may be corrupted by the azimuthal variation, which seems to have an amplitude of as much as 40% in certain cases and is poorly constrained as to how the phase of the effect changes with viewing geometry. We continue to spend a reasonable amount of effort trying to understand the systematics of this effect, at least to the extent possible to avoid having it bias our primary results.

**Improvements to image processing system:** The powerful and flexible image processing system which we developed, support, and continually upgrade under this RTOP provides a major facility for about ten researchers. We hope to maintain the ability to support both resident and visiting scientists interested in ring studies, and to be able to provide analysis in support of research tasks initiated by others than imaging team members. For instance, we recently were able to rapidly address questions posed by members of the PPS team on some apparent anomalies in the Uranian ring structure, and by a member of the Electric Field Analyser team on the possibility of detecting extended regions of dust at the location of Voyager ring plane crossing. Most recently, we have implemented on-line inspection and display programs for accessing the full stellar and radio occultation data sets. We actively pursue the use of computer telecommunications and data transfer between interested ring scientists. The programmer/analyst time required to maintain this system and support occasional users, as well as to actually perform much of the basic data analysis, is funded partially under this RTOP and is our fundamental limitation. For the sake of economy, we will continue to run interactively on the Ames Space Science Division VAX'es (11/785 and 8600) for the near future.

#### Bibliography:

Cuzzi, J. N. (1985) Rings of Uranus: not so thick, not so black, *Icarus*, 63, 312-316

Cuzzi, J. N. and J. A. Burns (1986) Charged Particle depletions surrounding Saturn's F ring - evidence for a moonlet belt; *Icarus*, submitted

Lissauer, J. J. (1985) Can cometary bombardment disrupt synchronous rotation of planetary satellites? *J. Geophys. Res.*, 90, 11289-11293

Ockert, M. E., J. N. Cuzzi, and C. C. Porco (1986) Uranian rings: photometry from Voyager; paper presented at Paris DPS meeting, October 1986

Porco, C. C., J. N. Cuzzi, M. E. Ockert, and R. J. Terrile (1986) The color of the Uranian rings; *Icarus* (submitted)

Showalter, M., J. N. Cuzzi, E. A. Marouf, and L. W. Esposito (1986), Satellite wakes and the orbit of the Encke gap moonlet; *Icarus*, 66, 297-323

Showalter, M., J. A. Burns, J. N. Cuzzi, and J. B. Pollack (1986), Jupiter's ring: new results on structure and particle properties, *Icarus*, in press

Shu, F. H., L. Dones, J. J. Lissauer, C. Yuan, and J. N. Cuzzi (1985), Nonlinear spiral density waves: viscous damping, *Astrophys. J.*, 299, 542-573